Comparison between different survivability measures on a generic frigate

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COMPARISON BETWEEN DIFFERENT SURVIVABILITY MEASURES ON A GENERIC FRIGATE

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SUMMARY

Choosing suitable survivability measures is a demanding task that has to start early in the ship design process. Throughout the design process there is a need for compromises that will define and sometimes limit future operations or capabilities. In this study generic survivability measures are compared. The study also examines the sensitivity of the calculated probabilities to changes in the threat description. The result shows that it is important to investigate the total effect of a hit over a set of relevant ship functions defined for example by survivability levels. The calculations for different threat definitions show that the changes in survivability are substantial when the threat definition is changed. Moreover, the effects of different hit assumptions differ between weapon types. This must be treated as an uncertainty which also should be reflected in the output and weighted into the decisions made, based on the survivability analysis.

1. INTRODUCTION

Choosing the right level of survivability for a naval ship and suitable survivability measures is a demanding task that has to start early in the ship design. Also, decisions regarding survivability are dependent on other ship design and capability decisions. Subsequently, throughout the design process there is a need for many compromises that will define and sometimes limit future operations or capabilities [1, 2].

Military safety and survivability guidelines, such as the NATO Naval Ship Code (NSC) [3] and the NATO guideline Survivability of small warships and auxiliary vessels, described by Manley [4], as well as naval specific class codes, such as those of Lloyd's Register [5] and Det Norske Veritas [6], discuss and describe survivability measures. However, even though that, for example, the NSC is goal based the methods for assessing the effectiveness and for prioritizing and selection of measures is left up to the naval administrations [7].

To aid in selecting survivability measures the aim of this study is to investigate the difference between typical survivability measures for a generic frigate, Figure 1. The study examines how the survivability is affected by changes in survivability design and changes in threat type and threat definition.

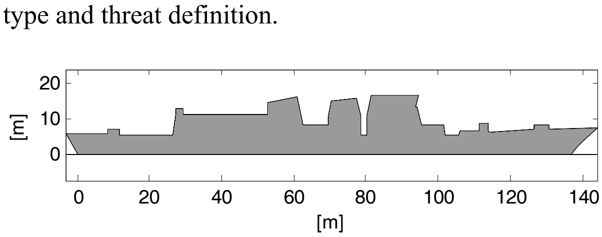

Figure 1: Frigate profile.

The effect of survivability measures is in this study defined as, and limited to, the reduction of kill probability $P_{K|H}$ as defined in Section 2.1 for the basic ship functions: buoyancy, manoeuvre, communications systems and weapon systems as well as the survivability levels 2 and 3 as defined in section 2.1. The study also examines the sensitivity of the calculated kill levels to changes in the threat description in terms of input hit probability distribution.

In a naval ship design project vulnerability programs, such as Survive [8], Prevent [9] or Aval [10], are often used to investigate survivability aspects of the design. The programs has strengths and weaknesses dependent on aspects such as their respective aims, modelling assumptions, level of detail that can be modelled, effects modelled and quality of validation. There are comparative studies between for example different programs and experiments. However, such studies are most often not possible to publish openly. In order to avoid classified information this study does not strive to represent the work of an actual ship design project. This study focus on relative probability values between different survivability approaches on a principal level on a generic ship. The resulting probabilities are not discussed in absolute terms or in relation to a specific ship.

The study is limited to above water threats and hits for three types of weapons systems: Anti-Ship Missile (ASM), 12.7 mm machinegun and hand-held anti-tank grenade launcher (RPG). These weapon systems are chosen in accordance with the concept of operations for the investigated ship type. The calculations of $P_{K|H}$ are performed with the lethality program Aval [10]. The model is a simplified volume-function model. The ship model created is made up of a series of rooms, where each room is a volume that also represents a systems. Therefore, the level of detail of the models consists of systems rather than components. No form of physical connections, such as cables and pipes, are simulated.

In the analysis the survivability measures that are implemented comprises of: change of system installation position in ship; redundancy and separation; and physical protection of vital ship systems.

In Section 2, ship survivability theory and implementation is described to form a base for the study. In Section 3, the methodology and simulation conditions are described. The results of the vulnerability calculations are presented and analysed in Section 4. Finally, Section 5 discusses the achievements made during the current investigation, followed by the conclusions, which are presented in Section 6.

2. SHIP SURVIVABILITY

2.1 THEORY

It is not possible to treat vulnerability and recoverability as constant and assume that a hit equals a ship kill [11-15]. To meet the new challenges in today's warfare, including asymmetric and littoral warfare, survivability must be examined more closely and constitute a timely contribution to the system engineering process [13, 16].

Survivability is often discussed in terms of susceptibility, vulnerability, and recoverability of the ship, see for example [3, 11, 12, 14-16]. The concepts are in this study defined according to:

- Susceptibility is the inherent inability of the ship (including tactical measures) to avoid detection, identification, classification and protective measures to avoid a hit. The susceptibility governs the probability of a hit (P_H).
- Vulnerability is the inherent inability of the ship to resist damage and governs the probability of damage given a hit ($P_{K|H}$).
- Recoverability is the ability of the ship and its crew to return the ship to operational capability and governs the probability of damage repaired (P_R). Recoverability must generally be defined in a relation to available time.

The, instant, killability of the ship is the product of probability of a hit (P_H) and the probability of damage given a hit ($P_{K|H}$). Survivability (P_S) is the opposite of killability and, if only primary and secondary effects are studied without the recoverability, is given by

$$P_S = 1-(P_H \bullet P_{K|H}). \quad (1)$$

If also the recoverability (P_R) is included survivability is given by

$$P_S = 1-(P_H \bullet P_{K|H} \bullet (1-P_R)). \quad (2)$$

A ship kill does not need to be total and can therefore be defined to different severity levels such as: system kill where one or more components are damaged and results in system failure; mission kill where the ability to solve a particular mission is killed; or total kill where the ship is lost or must be abandoned [11, 12]. Analysing different ship survivability levels (or kill levels) must be based on identified critical systems and components [15].

The survivability levels used in this work are defined as:

Survivability level 1: Sustained ability to rescue personnel and prevent complete loss. Minimum remaining ship functions: 50% of the pump capacity; 75% of the regular crew; and 50% of the life rafts.

Survivability level 2: Sustained ability for mobility: Minimum remaining ship functions: survivability level 1; 50% of the propulsion capacity; 50% of the rudder capacity; and 50% of the electric power or emergency power.

Survivability level 3: Sustained self-defence capabilities. Minimum remaining ship functions: survivability level 1 and 2; and 50% of self-defence systems (with electrical power, associated sensors and target systems and ammunition storage).

Survivability level 4: Sustained fighting capability. Minimum remaining ship functions: survivability level 1 and 2, 100% of command and control, 100% of communications, 50% of weapon systems and associated sensors and ammunition storage; and navigation.

2.2 SURVIVABILITY IMPLEMENTATION AND BEST PRACTICE

There are a number of measures which will increase the survivability of a naval ship. For susceptibility these include: early warning, jamming and decoying, signature management, tactics, adaptation, and combating weapons systems. For vulnerability, they include redundant systems, placement of components, separation of key components, passive protection, and protective components [11, 13].

In order to implement survivability effectively there is a need for a systematic and developed method to which naval ships are designed and built. It is important that the ship is analyzed from all three survivability perspectives in order to identify key actions early in the design process, using a methodology derived from System Engineering [13]. The analysis involves analyzing the tasks and environments in which the vessel is intended to operate in and to balance the various tools as well as the design principles. This will emphasize the ability to respond effectively to threats and also to ensure that these measures should not counteract each other. For example, separating the propulsion machinery will likely increase the size of the vessel. This in turn may lead to the ship's radar cross-section increasing [11].

It is also crucial that measures to decrease the vulnerability of warships are implemented early in the design process. This in order to create conditions for survival during the design and construction process of naval ships. Later in the process it becomes more difficult to implement vulnerability reducing measures. These measures often involve placing of systems and can consist of separation of propulsion system or adding redundant systems, such as power distribution [17].

The implementation of survivability is often a matter for the national authority. In the past often also the design have been executed and tested by the national authority, but recently that has changed. It is today more common that nations uses classification society's rules and standards when naval ships are built and designed, as a result of shrinking budgets. This is despite that the classification societies mostly set standards which in many cases represents a minimum level. However, the rules ensure that suitable materials and a suitable design is used and is verified against the current class rules or international and commercial standards [18, 19]. In the naval specific class rules there are sections directly focused on survivability, for example Military design in Lloyd's Register [5] and Combat survivability in Det Norske Veritas [6].

The classification societies offer, in their notations for warships, a variety of requirements which can be attributed to the survivability-increasing measures. These requirements are, in many cases, perceived as easier to understand and follow especially among civilian shipbuilders and shipyards. Depending on classification society, the classification notations apply both to physical protection but also requirements for different types of configurations and arrangements, such as on separation and redundancy. For example has Lloyd's Register [5] a specific notation for physical protection and Det Norske Veritas [6] has a specific discussions on how to achieve separation and redundancy. The rules do not explicitly cover military systems, but indirectly they support the military operation by, for example, ensuring survivability of the propulsion and power distribution on a ship [18, 19].

3. SIMULATION CONDITIONS

3.1 A GENERIC FRIGATE

The ship used in the vulnerability analysis presented is a generic frigate illustrated in Figure 1 and described in Tables 1 and 2.

Table 1: Ship specifications

Length, waterline	137 m
Beam	14.8 m
Draught	5.6 m
Displacement	3900 tons
Crew	120
Number of watertight subdivisions	15
Propulsion and Power: 2 shafts and propellers; 2 GE LM 2500 GTG; and 4 Diesel generators MTU 396 1250 KVA.	
Weapons: 8 RBS 15 MK3; 1 Bofors 57mm navalgun MK3; and 1 Phalanx CIWS 20 mm.	

Table 2: Plate thickness, steel

Hull sides	8 mm
Bulkheads	4 mm
Watertight bulkheads	12 mm
Weather Deck	10 mm
Superstructure	6 mm

The calculations have been performed on four different configurations with significantly different approaches to survivability.

Configuration 1, basic alternative 1: This alternative has the simplest design concerning survivability. All the main propulsion engines are placed in the same watertight compartment and the reduction gears are placed in a separate compartment. The power supply systems have the generators in one compartment and the main switch board situated in another watertight compartment. This means that the propulsion and electrical systems will be vulnerable to a single hit. However, this configuration has two Combat information centres (CIC).

Configuration 2, basic alternative 2: This configuration has the survival focus on basic separation and redundancy. Configuration 2 has separated the two propulsion systems, each system consists of a main engine and a reduction gear, in two compartments situated next to each other. The electrical power distribution systems are also divided into two compartments with one complete system in each compartment, which are situated next to each other. In this configuration each system will be less vulnerable to a single hit.

Configuration 3, separation and redundancy: This enhanced version has a survival focus based on extended separation and redundancy of critical systems. The two propulsion systems are separated in different compartments with one watertight compartment between them and both have reduction gear and engine in the same compartment. The electrical systems are divided in two compartments with two watertight compartments between them. The generators and main switchboard in the same compartment. This configuration compared to Configuration 2 has a greater separation between the different systems

Configuration 4, physical protection: The survival focus is put on physical protection of identified critical systems as described in Section 3.2. The physical protection consist of an increased plate thickness of the bulkheads surrounding the compartments where the systems are placed. The thickness of these bulkheads are 27mm. The compartments that have been reinforced comprise of one of the engine rooms, the CIC and all three ammunition lockers. Regarding redundancy and separation this configuration has a similar placement with respect to propulsion and electrical systems to Configuration 2.

3.2 SHIP TASKS AND RESULTING CRITICAL SYSTEMS

To implement survivability measures the ship intended operation in relation to the ship systems have to be analysed. The analysis is described in three steps: area of operations and concept of operations; critical functions; and critical systems.

First the analysis of the area of operations and the concept of operations have been defined the threats and capabilities. The analysis is based on littoral operations with the following tasks:

- Surveillance and Reconnaissance Operation;
- Protection of Shipping Operation;
- Coastal defence operation.

Based on these tasks [20] the following functions are assessed to be important:

- Protection of personnel: The function includes the possibility of abandoning the ship and having systems that support recoverability measures.
- Mobility: The ability of the ship to float but also make forward / reverse speed through the water and be able to manoeuvre, which requires systems such as propulsion, electrical power and control.
- Self-defense: Having the ability to operate the ship's weapon systems and sensors for self-defence.
- Weapon effect: The ability to use the vessels weapons systems and sensors, in order to exercise command and control in the area of operations.

The last and third step depends on which systems different functions are dependent on, and therefore which systems should be considered critical or essential to solve the tasks. One way to do this analysis is to perform a critical component determination [15]. This method can be used to examine the systems and the components that are of particular importance for the ship in accordance with the ship's concept of operations, and how different degrees of redundancy impact the ship's survivability [15]. For this study assessments have been made according to a three-point scale. The systems are graded according to how important they are for the chosen assignments.

- One point: the system helps to solve the task, but is not essential.
- Two points: the system is always used but is not necessary for the task to be solved.
- Three points: the system is crucial for meeting the assignment.

The results are then used to assess the significance of the components at the various tasks. The subtotal value for each function is then divided by the number of redundancies in each system [20]. The analysis show that the vessel's technical functions (hull, propulsion and electrical power) receive a high value with regard to the subtotal, because they are fundamental to a ship's ability to operate at sea. However, the various weapons and sensor systems generally receive a lower value since their importance varies depending on the mission profile. However, as a result of the redundancy in vessel functions the total sum is higher for weapons and sensor systems than ship systems. The five most critical functions for the ship studied are shown in Table 3.

Table 3: The five most critical systems, in prioritizing order.

CIC/OPS room
Naval gun
Ammunition lockers
Bridge
Surveillance radar

3.3 THREAT

The intended operation types and threats must be analysed with respect to aspects such as weapon type, but also to the hit probability for different compartments. The traditional ship threat is an ASM usually equipped with a radar or infrared seeker. Most nations have models as to how such missiles are assumed to operate. The models are used to guide the design of protection systems, but can also be used to make assumptions for a probabilistic threat description. An example of an assumed hit position distribution for ASM is presented by Boulougouris and Papanikolaou [12]. However, in a littoral or asymmetric scenario there is also exposure to unguided weapons developed for land situations such as RPGs [21]. Therefore, the probability distribution of hit position for short range attack will be dependent on the shooter's perceptual predisposition, believes and assumptions rather than technical aspects.

In the simulations in this study the effect of three different weapons are examined, a small ASM, a 12.7mm Machine gun and a RPG, see to Table 4.

Table 4: Definition of threat weapons.

Weapon	12,7mm	RPG	ASM
Speed at impact	800m/s	250m/s	600m/s
Shots per salvo	30	1	1
Warhead type	Kinetic	Shape charge	Pressure and shrapnel
Weight/size	49g	70mm	150 kg
Shrapnel weight	-	-	175g
Shrapnel size	-	-	35mm
Shrapnel, number of	-	-	580

In this study the effect of three different length-wise hit distributions (normal, even and triangular distribution) for ASM and RPG hits is compared to determine the importance of a correct assumption.

4. SIMULATIONS, ANALYSIS AND RESULTS

The calculations of PK|H are performed with the lethality program Aval [10]. The level of detail of the models consists of systems rather than components. No form of physical connections, such as cables and pipes, are simulated. Depending on the system set to each compartment the system kill probability varies. For example, the kill probability for propulsion given a volume hit is lower than the kill probability for weapons electronics [22].

All results are given as an analysis ten seconds after hit. Therefore only direct effects of the hit are considered and not secondary effects, such as effects of fires spreading and affecting more systems.

4.1 RESULTS OF THE VULNERABILITY CALCULATIONS

The result of simulations is presented, as the probability of kill given a hit, for ship functions and survivability levels. The analysed ship functions are buoyancy, manoeuvre, communications and weapon systems, where the definition for buoyancy kill is the standard Aval definition. Manoeuvre kill and communication kill is developed for this ship and each ship configuration so that the function is killed if any vital sub system or combination of subsystems is killed. Weapon system kill is defined as a kill if at least one of the ship's three weapon systems: close-in protection weapons system, ASM and dual-purpose naval gun. The survivability levels analysed are survivability level 2 and level 3 as defined in Section 2.1.

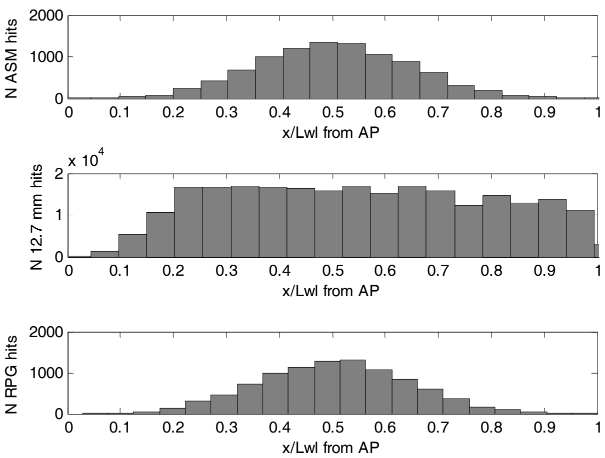

Figure 2: Distribution of hits along the ship length axis in simulations. Top: (a) ASM, middle: (b) 12.7 mm, and bottom (c) RPG.

The results in Sections 4.1 (a) - (c) are calculated using the three length wise distributions given in Figure 2. The ASM and RPG distributions are a result of an aim point in the middle of the ship with a normal distribution with high standard deviation horizontally and small vertically. The 12.7 mm 30 shot salvo starts at the bow and moves aft. For the 12.7 mm hit distribution it can be seen that the amount of hits increases in the locations with a super structure.

4.1 (a) ASM

The simulated ASM hits are distributed along the ship's starboard side according to Figure 3.

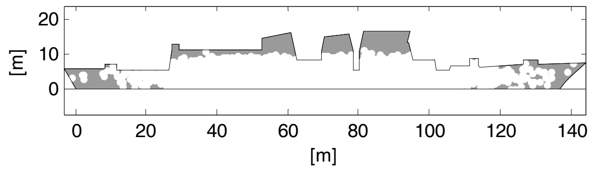

Figure 3: Hull profile with ASM hit positions (white dots).

The kill probability for ship functions and survivability levels given an ASM hit are shown in Figure 4 and 5 respectively. The ASM hit results in the highest level of kill probability of the investigated weapons.

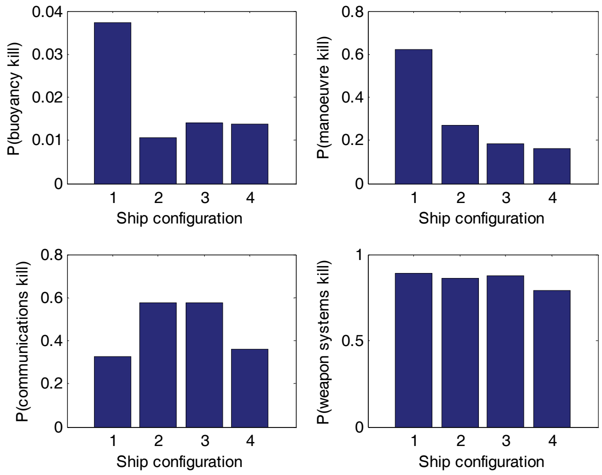

Figure 4: Probability values (PK|H) for buoyancy kill manoeuvre kill, communication kill and weapon system kill for the four ship configurations as a result of an ASM hit.

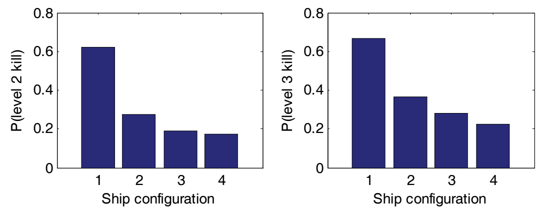

Figure 5: Probability kill values ($P_{K|H}$) for survivability level 2 and 3 a result of an ASM hit.

4.1 (b) 12.7mm machinegun

The kill probability for ship functions and survivability levels given by a machine gun salvo (as defined by Section 4.1) are shown in Figure 6 and 7 respectively.

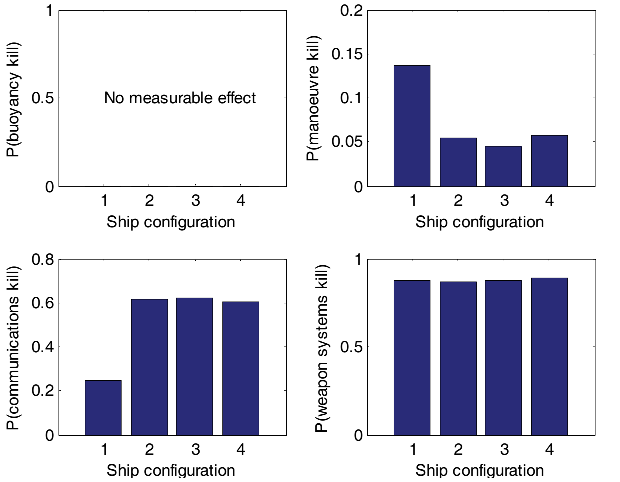

Figure 6: Probability values ($P_{K|H}$) for buoyancy kill manoeuvre kill, communication kill and weapon system kill for the four ship configurations as a result of a 12.7 mm machine gun salvo. No measurable effect means that all probabilities are below 0.01.

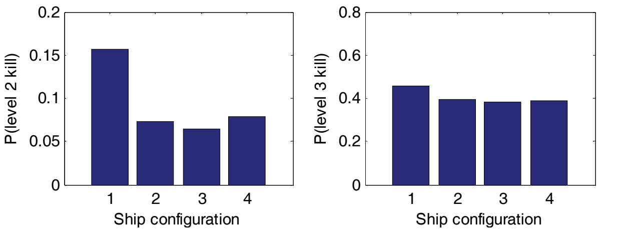

Figure 7: Probability kill values ($P_{K|H}$) for survivability level 2 and 3 a result of a 12.7mm machinegun salvo.

4.1 (c) RPG

The kill probability for ship functions and survivability levels given a RPG hit are shown in Figure 8 and 9 respectively. The RPG hit results in the lowest level of kill probability of the investigated weapons.

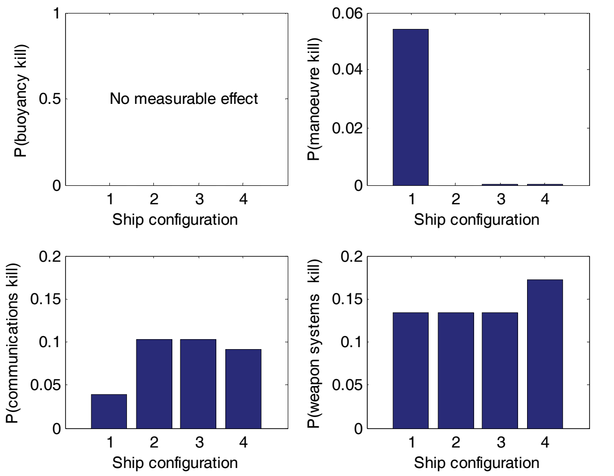

Figure 8: Probability values (PK|H) for buoyancy kill manoeuvre kill, communication kill and weapon system kill for the four ship configurations as a result of a RPG hit. No measurable effect means that all probabilities are below 0.01.

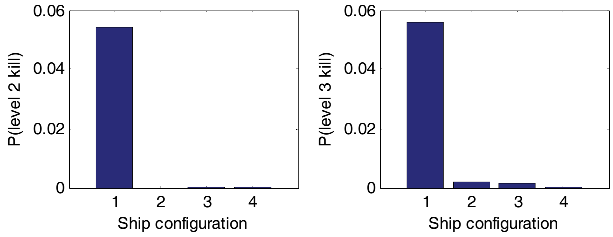

Figure 9: Probability kill values ($P_{K|H}$) for survivability level 2 and 3 a result of a RPG hit.

4.1 (d) The effect of length-wise hit distribution

In order to examine the sensitivity of the calculated probabilities to changes in the threat description in terms of input hit distribution the kill probability is recalculated. Recalculations are performed for ship configuration 4 and an ASM hit and for ship configuration 1 and a RPG hit.

Here the change in kill probabilities is examined between three different hit distribution assumptions: (i) the normal hit distribution according to Figure 2.a and 2.c; (ii) an even hit distribution along the ship; and (iii) a triangular hit distribution according to Boulougouris and Papanikolaou [12].

The kill probabilities for the two new hit distributions (ii and iii) are calculated by adjusting the relative weight $w(x)$ of each Monte Carlo-cycle result according to

$$w(x) = f_{new}(x)/f_{norm}(x), \quad (3)$$

where x is the hit position; $f_{new}(x)$ is the frequency at x for the new distribution (ii or iii); and $f_{norm}(x)$ is the simulated ASM distribution according to Figure 2.a or RPG distribution according to Figure 2.c.

The resulting kill probabilities for the three hit distributions are for the ASM shown in Figures 10 and 11 and for the RPG in Figures 12 and 13.

As can be seen in Figure 10 given the same threat and ship configuration the buoyancy kill probability increase as much as nine times when the distribution is changed from normal distribution (assumption i) to the even distribution (assumption ii).

The effect of different distribution assumptions is, however, not as big for the survivability levels shown in Figure 11. This because the survivability levels are governed by changes in the manoeuvre survivability as discussed in Sections 4.1 (a) – (c).

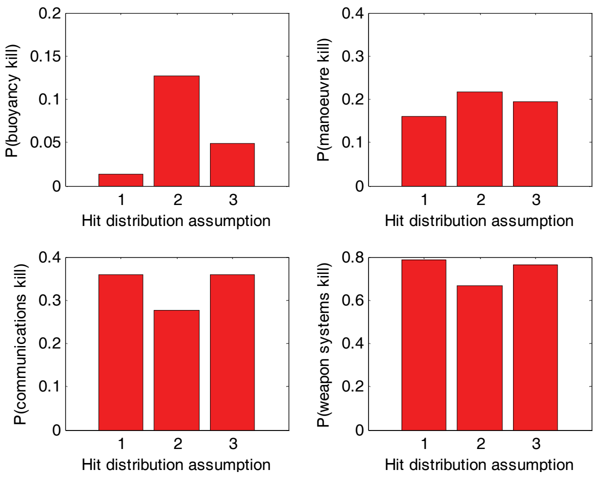

Figure 10: Probability values ($P_{K|H}$) for navigation kill, propulsion kill, weapon systems kill and buoyancy kill for the ship configuration 4 as a result of an ASM hit.

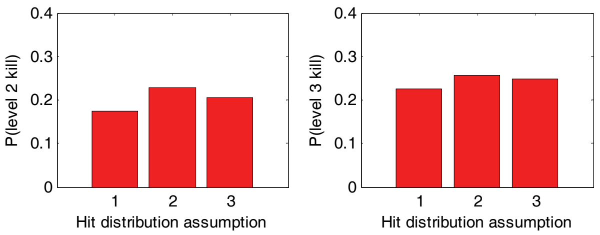

Figure 11: Probability kill values ($P_{K|H}$) for survivability level 2 and 3 for the ship configuration 4 as a result of an ASM hit.

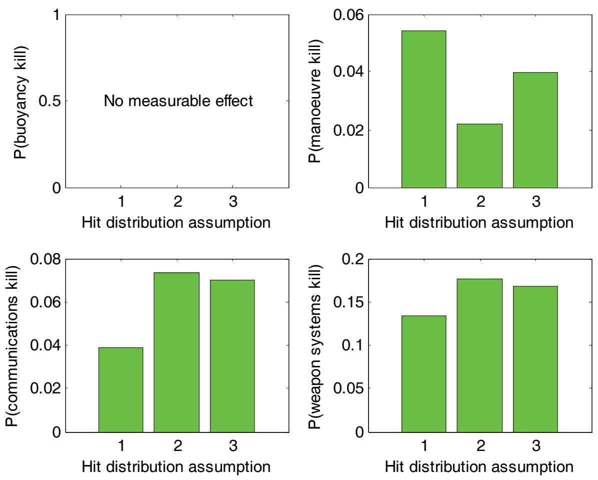

Figure 12: Probability values ($P_{K|H}$) for navigation kill, propulsion kill, weapon systems kill and buoyancy kill for the ship configuration 1 as a result of an RPG hit. No measurable effect means that all probabilities are below 0.01.

When Figures 11 and 13 are compared it can be seen that the highest survivability for an ASM hit is achieved for the normal hit distribution (assumption i) and for RPG hits for an even hit distribution (assumption ii).

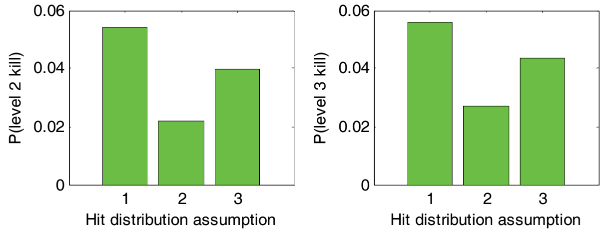

Figure 13: Probability kill values ($P_{K|H}$) for survivability level 2 and 3 for the ship configuration 1 as a result of an RPG hit.

4.2 RESULTS

The three different survivability concepts (change of system installation position in ship, configuration 2; redundancy and separation, configuration 3; and physical protection of vital ship systems, configuration 4) affect the ship design in different ways. In general the results show that physical protection of vital ship systems lead to the lowest killability. This as a result of the protection provided to the vital systems, but also to other systems as the physical protection introduced stops shrapnel from spreading in the ship. However, in a ship design situation it is not obvious that the extra survivability achieved by the physical protection outweighs drawbacks, such as extra weight. Therefore, in a real ship project there is a need to combine different survivability measures in a balanced manner appropriate to the ship at hand.

For the ship and weapons analysed the probability of buoyancy kill is low. This as a result of relatively local effects of the weapons and that only above waterline hits are considered. As seen in Figure 4 Configuration 1 is the configuration with highest buoyancy kill probability. This as a result of the differences in propulsion design. The differences results in higher probability for shrapnel damaging the lower compartments.

If only the survivability of the basic ship functions is examined then the simulations show that the survivability for the four ship configurations differ between the different weapons. However, when instead the ship survivability levels are examined, the trend is clearer and shows an increasing survivability from ship configuration 1 to 4, especially for the ASM attack.

It is also clear from the results that manoeuvre is the dominating effect on both the studied survivability levels. The only exception is for the probabilities as a result of a machine gun salvo. The kill probability for survivability level 3 is more than twice as high as the manoeuvre kill probability. This means that particularly the self defence system is sensitive to the machine gun salvo.

From the results the effect of the redundancy in communication capability for Configuration 1 is clear. The implemented redundancy reduces the kill probability by at least 40 percent.

Therefore, the results shows that it is important to investigate the total effect of a hit over a set of relevant ship functions defined by, for say survivability levels. Central ship functions also have to be examined to find functions with low survivability. For example, from the analysis it is clear that focus must be put on increasing the survivability of the systems creating manoeuvrability, such as propulsion and steering if the probability for survivability level 2 and 3 are to be increased. This shows the utility of this type of analysis since it is not possible to protect all functions and components on a ship, so it is necessary to prioritize the most fundamental components.

A valid understanding of the ship's survivability can only be formulated if there is an understanding as to how the survivability levels are affected by design choices for specific systems. Without such an understanding survivability measures may be ineffective. However, it is also important that central functions have to be examined to find functions with low survivability, to prevent important functions from being eliminated with a single hit.

The calculations for different threat definitions show that the changes in survivability are substantial when the threat definition is changed. Moreover, the effects of different hit assumptions differ between weapon types which means that no general conclusions can be made regarding which hit distribution is the most dangerous; it depends on both weapon type and the particular ship functions examined. This fact puts extra demands on the analyst and the technical intelligence input to the simulations. It is not likely that the hit position probability can be exactly defined, especially for weapons where the shooters perceptions have a substantial impact, such as for the RPG. This must be treated as an uncertainty which also should be represented in the output and weighted into the decisions made, based on the survivability analysis.

One reason for the differences in kill probabilities between the three hit distributions could be the fact that the effect of the two weapons investigated are relatively local, i.e. the effect of the hit is to a large extent decided by the hit location.

As a result of the, for some cases, relatively high effect of threat definition uncertainty, single quantitative results should not be given too much focus. It is more valid to use the results for explaining strengths and weaknesses with different design alternatives or for identifying the solution which is the least sensitive to changes in the threat, i.e. the robust solution [23].

5. DISCUSSION

For naval ships survivability is crucial to maintain the ability to fight in a hostile environment. It is therefore important early in the design process to determine what survivability level it is possible to achieve for the intended operations. In order to do this there must be a systematic analysis of the ship.

The simulations in this study were performed on a generic ship design with a simplified tool. Values for a specific ship could both be higher and lower dependent on the design choices made. As a result of the simplified tool the calculated probabilities should only be used for comparing solutions and ship concepts based on the same simplifications, they should not be seen as absolute values. In a specific ship design it is also important that the redundancy in the ship functions also is represented in the wiring and piping.

Survivability is only one of many aspects that have to be covered and analysed in a ship design [2, 7]. Other important aspects include areas such as combat effectiveness and cost. There is a need for a validated knowledge model for each of these areas [2]. In such a knowledge model for operational risk, a vulnerability analysis as performed here plays an important role. Since there are a numerous types of threats that can affect a naval vessel, it is important to analyse the threats appropriate to the specific ship. However, the analysis of survivability must also include a susceptibility analysis and a recoverability analysis. In sum it is obvious that the key term here is knowledge, the aim of the different analyses must always be to provide the decision process with knowledge on how different designs contribute to solving the tasks.

Invalidated input can lead to selecting a ship configuration that is unsuitable, especially if the survivability of ship functions is investigated instead of ship survivability levels. Defining a relevant threat is as important as it is a challenge, see Law [24] for a similar discussion in respect to helicopter survivability. There is limited open knowledge on which of the three hit distributions (i to iii) is the most correct one. It is reasonable to assume that the actual hit distribution is affected by the tactical situation, the weapon type and the susceptibility of the ship. If that assumption is correct the hit distribution will wary between cases and between ships.

The importance of investigating the kill probability of ship survivability levels underlines the importance of examining the interdependencies of ship functions as well as identifying critical ship functions from operational scenarios. Without correct interdependencies and critical functions the probabilities for different ship survivability levels will be misleading.

As mentioned above, an alternative way of using the result is to analyse the robustness of different solutions to changes in threat and scenario. This would then meet the demands of a resilient solution where surprises in the future are assumed and also recognise the substantial uncertainties in security analysis [25, 26].

A goal based approach permits in theory alternative arrangements, but the available and validated choices of verification methods often reduces that freedom [7]. Subsequently, even if a goal based code or guideline promotes survivability it may be a challenge to find a suitable analysis approach that can support decisions where compromises has to be done between, for example, maritime safety and survivability. Therefore, there is an important difference between goal based approaches and the risk-based approaches promoted by the International Maritime Organization [27-29] where risk-based approaches stipulates that risk should govern decisions on safety and security.

6. CONCLUSIONS

The calculations show that the survivability of a naval ship depends on a high number of parameters and are therefore often surrounded by uncertainties. Therefore it is important to evaluate and determine what kind of components and systems, that should be prioritized in order to enhance the ship's survivability.

The result shows that it is important to investigate the total effect of a hit over a set of relevant ship functions defined by, for example, survivability levels. Survivability levels can be used to analyse the survivability measures that have to be implemented when designing a ship. But it is also important that central functions have to be examined specifically to find functions with low survivability, to prevent important functions from being sensitive to a single hit.

The calculations for different threat definitions show that the changes in survivability are substantial when the threat definition is changed. This fact put extra demands on the analyst and the technical intelligence input to the simulations. It is not likely that the hit position probability can be exactly defined, especially not for weapons where the shooter's perceptions have a big impact, such as for RPG's. This must be treated as an uncertainty which also should be represented in the output and weighted into the decisions made, based on the survivability analysis.

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